Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds)

The effects of sample dimension and gradation on shear strength parameters of conditioned soils in EPBM

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ABSTRACT: Mechanical properties of conditioned soils in EPBM tunneling consist of lots of unknowns. In this research, the tests has been arranged to fulfill of four goals. Firstly the effects of conditioning on the shear strength variation have been investigated. Secondly an investigation on effects of conditioning on shear strength parameters (C,φ) has been performed. In third step the results exerted from two previous stages have been compared for two shearing apparatuses of conventional and large shear boxes. The last goal of the research is exploration of effects of changes in conditioning parameters on shear strength. It is found that the C&φ for tested soils obtained from large shear box are usually greater than the results of the same soil in conventional shear test. This result is less significant for conditioned soil with compared to unconditioned soil and it is found to be a function of injected foam content.

1 INTRODUCTION

Determining the shear strength parameters of the conditioned soils usually lead to the use of conventional shear box tests because of no availability to large shear boxes. In order to use this apparatus, soil gradation must be modified based on the codes which demands to elimination of great mass of coarse particles. This elimination affects the shear strength parameters especially in conditioned soil. In this research the effects of sample dimension and soil gradation on properties of foam conditioned soils have been investigated. A modification on soil gradation has been done in samples of large and conventional shear boxes. The variables in this research are normal stress and the injected foam quantity in to each of soils.

2 MATERIALS AND PROCEDURES IN SOIL CONDITIONING

2.1 *Conditioning parameters*

- Concentration (C_f)
  This parameter is the content of foaming agent in water unit weight.
- Foam Expansion Ratio (FER)
  This is the volumetric expansion of a unit volume of foaming solution.
- Foam Injection Ratio (FIR)
  It consists of the ratio of injected foam volume to volume of the conditioned soil.

The last parameter is of great importance in successful soil conditioning.

2.2 *Laboratory foam generation system*

To produce a conditioner (foam) with specific and controlled parameters, a foam generating system in laboratory scale was designed and constructed. This apparatus has the ability of controlling foam properties along the production and can produce uniform foam. The schematic plan of this system which manufactured in soil mechanic laboratory of Tabriz University is shown in figure 1.

Foam generation is performed by mixing process of air and liquid (consist of foam agent) under pressure. In the first step the reservoir must be filled by foam Solution. Foam generation is performed by mixing process of air and liquid (consist of foam agent) under pressure. In the first step the reservoir must be filled by foam solution. A regulator controls the air pressure supplied to the reservoir. Liquid valve is opened and flow control valve is used to adjust the flow through the liquid flow meter to the foam generator unit inlet. The pressure in the air flow line is controlled with a control valve of liquid flow meter and measured by a pressure gauge. Air pipe valve is opened to allow the air to flow through the control valve and the air flow meter to the generator unit inlet. The pressurized air and foam solution then flow through the generator unit to produce the foam. The design of the foam generator allows the liquid and

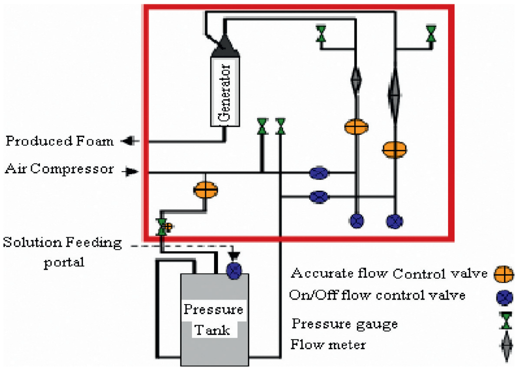

Figure 1. Schematic of laboratory foam generation system.

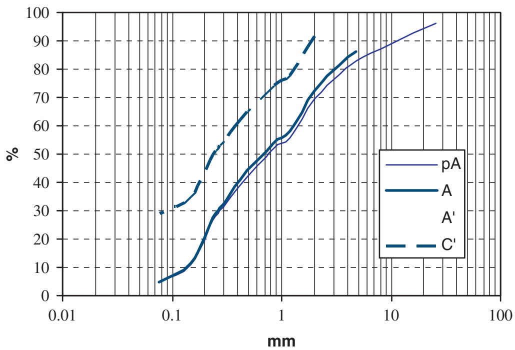

Figure 2. Particle distribution of soils used in this research.

air flow rates and pressures to be adjusted and monitored separately to control the properties of the foam produced.

3 SHEAR TESTS PATTERNS

In order to perform large shear box (300 × 300 × 150 mm) tests and conventional shear box (60 × 60 × 20 mm) tests the soil excavated from Tabriz metro line has been used. This soil labeled pA. Considering the maximum dimension of the soil particles with respect to the shear box dimension (large, conventional), soil gradation has been modified to A, A' (by elimination of the oversized particles) and C' (same as A' with 30% more in fine content). Particle size distribution for these soils has been illustrated in figure 2. Direct shear tests on soils A, A' and C' were performed using conventional and large shear boxes. The normal stresses on samples also were 37.52, 64.75, 119.29 and 228.28 (kPa).

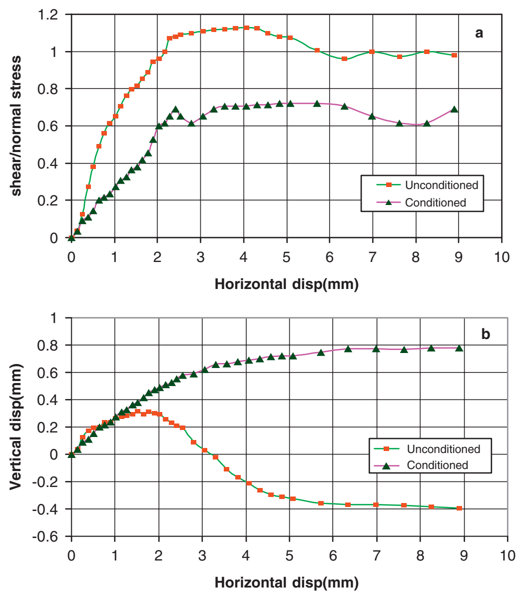

Figure 3. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil A' under normal stress 37.52 kPa.

4 RESULTS AND DISCUSSIONS

4.1 *Conditioning effects on shear strength variation trends*

The behavior of soil A' in conditioned and unconditioned state under different normal stress (37.52, 64.75 and 119.29 kPa) in direct shear tests have been shown in Figure 3 to 5. The variation of shear/normal stress ratio versus horizontal displacement has been investigated. The variation of vertical displacement with respect to horizontal displacement during shear test has been also considered. Figure 3 shows the results for soil A' in both conditioned and unconditioned state. A reduction of almost 0.4 in maximum values of stress ratios can be observed. The curvatures indicate some peak point in lower stress ratios in unconditioned soil test. This peak is going to disappear by increasing the stress level. But in conditioned samples there is no peak point in any stress level. It can be observed that increasing in stress level can convert the dilative behavior to contractive behavior. However the conditioned samples give a completely contractive behavior regardless of initial specific volume.

4.2 *Conditioning Effects on shear strength parameters*

Table 1 shows calculated C&φ for performed tests. The friction angle for peak and residual states are given.

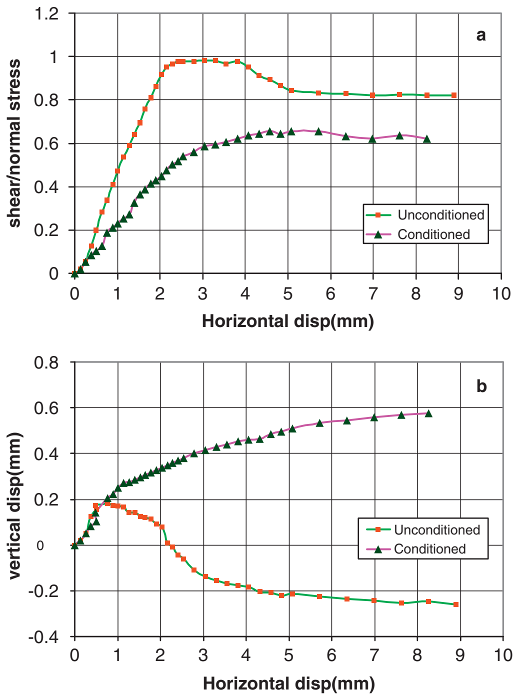

Figure 4. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil A' under normal stress 64.75 kPa.

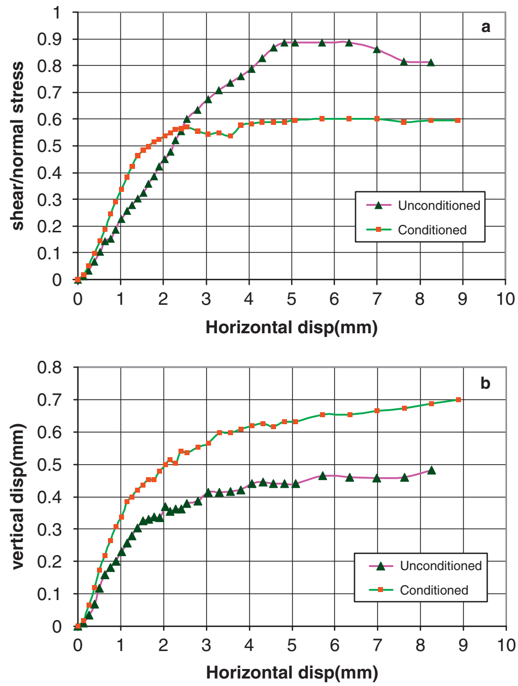

Figure 5. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil A' under normal stress 119.29 kPa.

The residual friction angle represents the state of the soils in excavation process.

Comparison of corresponding shear tests performed on both conventional and large shear boxes indicate that the large boxes give internal friction angle 6 to 7 degrees greater than conventional shear tests. However in the tests on conditioned samples this reduces to 3 to 4. Large apparatuses also result in lower cohesion in comparison to the standard samples. Also in conditioned samples this trend is traced but it is less intensive.

4.3 *Effects of variation in conditioning parameters on shear strength parameters*

The needed conditioner for soils used in tests has been predicted using the Kusakabe 1999 formula.

$$Q=\frac{a}{2}[(60-4.0X^{0.8})+(80-3.3Y^{0.8})+(90-2.7Z^{0.8})] \qquad (1)$$

Where X = the percentage of soil passing 0.074 mm; Y = the percentage of soil passing 0.25 mm; Z = the percentage of soil passing 2.0 mm; $a = 1.0$ for $C_u > 15$, $a = 1.2$ for $15 > C_u > 4$, $a = 1.6$ for $4 > C_u$

Using this formula for soil A, the FIR is 50%. Soil A has been tested with FIR equal 50%, 30% and 70% and results are shown in figure 6. For example in treatment with FIR = 30% an increasing of 0.11 in normal/shear stress ratios can be observed. Contrarily, with FIR = 70% no remarkable effect was observed. It is clear that increasing FIR do not change the normal/shear stress ratios while a little reduction on FIR has considerable effect on this ratio.

Figure 7 gives the results for another group of similar tests on soil A' with various FIR. If one apply the soil gradation A' to the Kusakabe formula, FIR will result in 40%. By increasing foam consumption.

In soil samples, a negligible reduction in stress ratios can be observed, but a little reduction in foam consumption will result a significant increase in these ratios. This relation in conventional shear tests is about 0.17. This means that consuming more foam indicates slight effect on shear strength of samples. During shearing, pore pressure will generate but in granular soil this will dissipate very quickly. In the presence of foam the dissipation of pore pressure will postpone and the shear strength will decrease in foamed granular soil. Comparison of changes in stress ratios in large and conventional tests shows that conventional direct shear tests results are more sensitive to the changes in

Table 1. Shear parameters.

	Fine content	Amount of conditioner	Normal stress	τ_μ kPa	Ø° peak	C kPa	Ø° residual
Large shear box	5	0	37.52	45.322	50.38	9.221	44.2
			64.75	72.888	48.39		
			119.29	125.08	46.36		
	5	50	37.52	26.095	34.82	4.42	31.1
			64.75	44.93	34.76		
			119.29	75.929	32.48		
Conventional shear box	5	0	37.52	42.281	48.41	14.62	37.4
			64.75	63.667	44.51		
			119.29	105.95	41.61		
			228.28	186.68	39.28		
	5	40	37.52	27.076	35.81	7.259	28.4
			64.75	43.066	33.63		

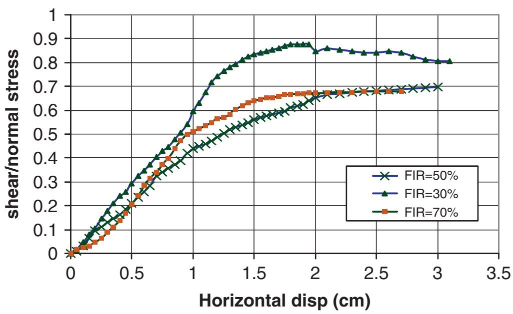

Figure 6. Variation in ratios of shear to normal stress versus horizontal displacement in large shear boxes on soil A under normal stress 64.75 kPa.

FIR than the results in the same samples in large shear test. The results for other tests give the same conclusion. This can be observed in Figure 8. This figure give some more information about soil C' which is similar to soil A' with some more fine content. It's obvious that the increasing FIR in samples that have excessive fine causes more significant loss in internal friction angle.

But in samples which have more fines this phenomena firstly occurs steeply but in FIRs higher than optimum this trend is not observed at all.

It can be concluded that the soil which have more fine content need less FIR to get a specific reduction of shear strength.

In order to study the possible effects of variation in foam expansion ratio (FER), a foam in three FERs of 5, 10 and 22 were prepared for similar shear tests on

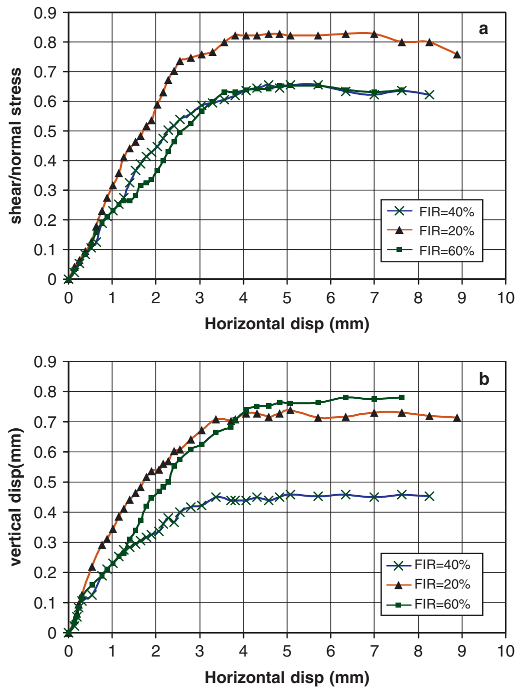

Figure 7. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil A' under normal stress 64.75 kPa.

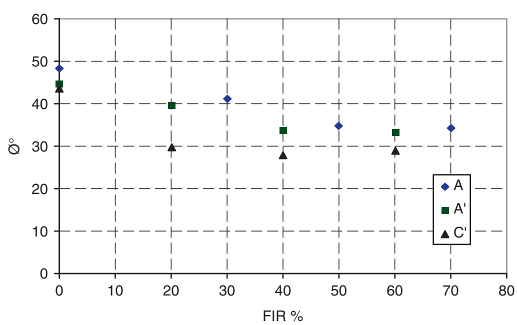

Figure 8. Internal friction angle versus variations in FIR.

soil C'. Figure 9 shows that a reduction on FER causes no effect on shear parameters and stress ratios.

The reason which can be stated is that the low FER indicates very wet foam so that it is unable to reduce the relative density and consequently increase the specific volume. On the other hand when the FER increases an unstable state occurs and consequently no changes in stress ratios happen. It is resulted that a FER closer to 15 gives a stable state for foam.

Figure 10 gives a view of obtained variations in stress ratios of conditioned samples during shearing

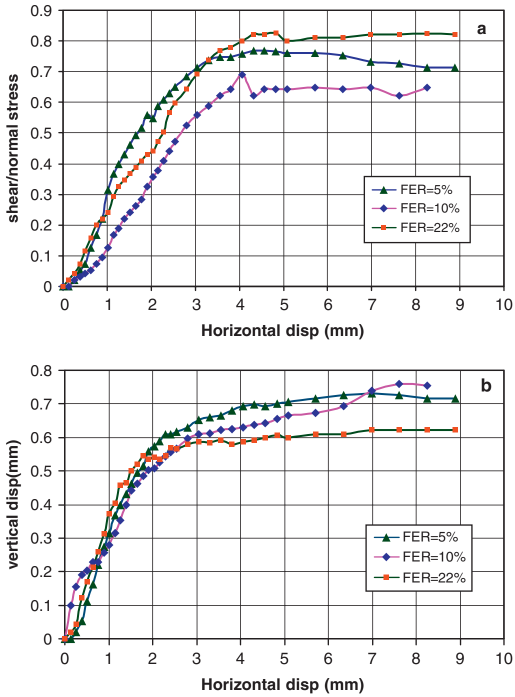

Figure 9. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil C' under normal stress 64.75 kPa.

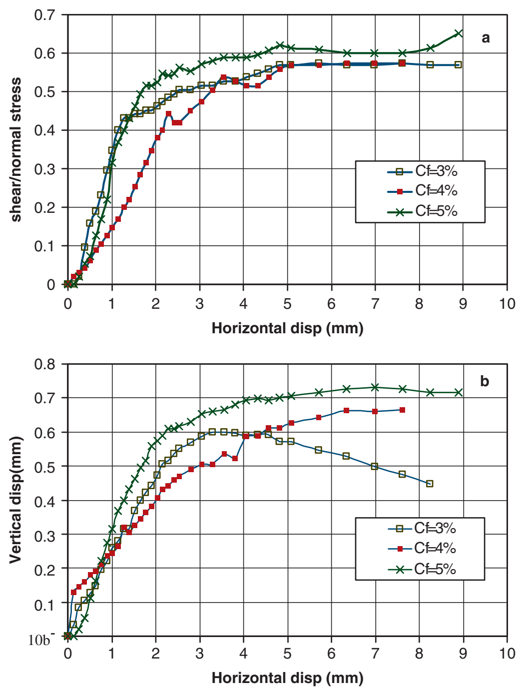

Figure 10. (a) Variation in ratios of shear to normal stress and (b) vertical displacement of sample cap versus horizontal displacement in Conventional shear boxes on soil C' under normal stress 64.75 kPa.

because of changes in Cf. Three tests performed on C' with three different initial Cf of 3%, 4% and 5%. If we consider the possible changes in stress ratios there is no significant difference between these samples. But the volume of samples tends to reduce during the test. The authors considered this logical as well as declaration of producers of conditioners.

5 CONCLUSIONS

1. The soil conditioning cause a decrease of 7 to 11 degrees in internal friction angle of soils. A loss of 49.1 kPa for the cohesion of conditioned soil was observed.
2. Decreasing FIR from its optimum given by Kusakabe formula, will greatly affect the trend of reduction in shear strength. But increasing in that quantity does not show remarkable effect. FER lower than 10 and more than 18 causes no conditioning and consequently the changes in strength are negligible.
3. Large shear test gives greater internal friction angle about 6 to 7 degrees in unconditioned samples and 3 to 4 angles in conditioned samples comparing conventional shear test.

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